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PHASE CONJUGATION SCALING FOR HIGH ENERGY LASERS(U)
UNIVERSITY OF SOUTHERN CALIFORNIA LOS ANGELES DEPT OF
ELECTRICAL ENGINEERING R W HELLWARTH 30 MAY 85

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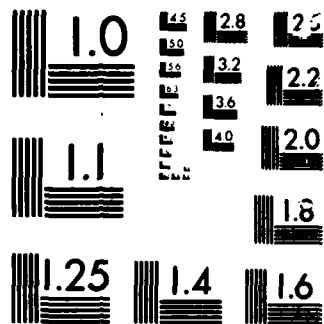
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
Phase conjugation of both cw and pulsed 10.6 micron lasers by stimulated Brillouin backscattering (SBB) has been attempted. Because of various technical difficulties, conclusive evidence of SBB was not found. However, theoretical studies in this project supported further the promise of SBB for obtaining diffraction-limited beams from high power infrared lasers. Several novel schemes for realizing 10 micron waveguides of several meters length were explored experimentally.		

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ROBERTS/ED HYATT

Gentlemen:

Please find the above mentioned reports prepared by Robert W. Hellwarth.

We thank you for your support of this important research and apologize for the delay in finalizing these reports.

Sincerely,

Harriet Vigoren
Contract and Grant Administrator

HV/sy

cc: Rosemarie Kelly - ONR Pasadena

Enclosure



A-1

1 Objective and Introduction

The objective of this project is to achieve the phase conjugation of a high power infrared laser beam (>10 kW cw power) in such a manner as to achieve near-diffraction-limited output from the laser medium. We have chosen the process of stimulated Brillouin backscattering (SBB) in an optical guiding structure to achieve this. This process is self-aligning, requires no ancillary pump or power source, and has already been demonstrated to produce a high fidelity phase-conjugate image of nanosecond visible laser beams.

The method for employing a phase conjugator to achieve a near-diffraction limited IR laser beam is explained schematically in Figure 1, in which are also given some typical beam powers showing that much less power ($\sim 10^3$ W) would need to be conjugated than the ultimate output power ($\sim 10^5$ W) of the laser system. Our object is to demonstrate phase-conjugation of an available pulsed or cw CO_2 10.6 micron lasers in such a manner as to make scale-up to longer pulses or higher powers plausible.

The process of backward stimulated Brillouin scattering works as shown in Fig. 2. For continuouswave (cw) powers below ~ 10 kW, a key element is an IR multimode waveguide containing a core in which sound waves exist that can mediate the Brillouin scattering with sufficient intensity. Practically any transparent substance will do this to a measurable degree. The difficulty is finding a substance transparent enough at 10.6 microns to form a guide for the several meters of length expected to be necessary to create stimulated backscattering with high conversion efficiency from our relatively low-power laser. To date, stimulated Brillouin backscattering (SBB), with or without guiding, has never been reported. Pilot SBB experiments with higher powers from an available pulsed CO_2 laser without guiding were therefore an intermediate objective.

2 Summary of Results (7/1/82 to 12/31/84)

Our studies were divided between obtaining stimulated Brillouin backscattering (SBB) at 10.6 microns first by scattering an existing cw 50W, single TEM_{00} mode, laser in a Brillouin medium contained in a waveguide, and secondly by scattering an existing pulsed laser (producing an approximately quarter microsecond, kilojoule TEM_{00} pulse) from liquid nitrogen without guiding. Although there was some evidence of success in the latter experiments, catastrophic instrumentation and laser failure, coupled with the necessity of retraining new doctoral and postdoctoral research assistants in mid-project, prevented verification by the end of the contract period. However, this experience and the continuing theoretical studies pursued in this project have convinced us that the techniques pursued here, of either guided or unguided SBB, will prove successful for phase-conjugation of high power infrared laser beams.

2.1. Infrared waveguides.

By way of introduction to the several IR guides we constructed, note that we are convinced that a successful scheme must employ dielectric guiding with a core material whose inverse attenuation coefficient α^{-1} cm (at the desired infrared wavelength) is much greater than the guide length L required to obtain stimulated Brillouin backscattering (~ 1 to 10 m for our 50 W, CO_2 laser). The dielectric wall or "cladding" which surrounds the core must, of course, have a lower refractive index than the core. However, the cladding need not have a bulk attenuation coefficient much smaller than 1 cm^{-1} , because the evanescent fields that leak into the cladding are so small in our case (i.e., where the core cross-sectional area S is much larger than λ^2 and the entrance beam solid angle is much less than the acceptance solid angle of the guide).

Because the core must have a larger refractive index than the cladding, and high-power infrared windows will not withstand high gas pressures, the core must most likely

have to be a solid or liquid. To obtain the required low infrared absorption, one would appear to be restricted today to liquids composed of rare-gas atoms (Xe, Ar, etc.) and homonuclear molecules (N_2 , O_2 , F_2 , etc.) Only one such liquid is stable at room temperature and pressure: bromine. Although, liquid Br_2 is difficult to purify and handle, there has been a recent demonstration that it can function at 2 to 3 microns as a waveguide up to 200cm in length. (Bridges, et al., Optics Letters 7, 566 Nov. 1982.)

We considered theoretically dozens of candidate schemes for realizing filled 10.6 micron waveguides, of diameters 0.1 to 1 mm, and having low loss in 1 to 100 m lengths. Of these we made experimental studies on the following types without achieving a satisfactory result:

2.1.1 Liquid nitrogen in VICOR glass warmed to create a thin gaseous envelope around the guiding and scattering liquid core.

We purchased meter-long tubes of Corning Glass 7930 (called 'VICOR') having 0.8mm bore and 8mm O.D. VICOR is porous fused silica through which nitrogen gas has a flow constant about equal to 1 cm^3 nitrogen, per cm^2 area, per atmosphere pressure difference over one cm thickness at STP.

A VICOR tube was suspended vertically with liquid nitrogen flowing through in the holder whose design is given in Fig. 3. Our calculations show that the flow rate of N_2 evaporating from the liquid core and maintained by a near 1 atmosphere pressure difference (by pumping the region outside the VICOR) will maintain an N_2 gas layer between the core and the VICOR of about one IR wavelength when the outer wall of the VICOR rod is heated (by several mW) electrically to a temperature about $10^{-2}K$ above the temperature of the liquid nitrogen core. The liquid nitrogen was to be flowed slowly (0.1mm/sec) to replace the evaporated material. A small gravity head would maintain the flow.

A small temperature gradient from bottom to top was created to prevent the formation of bubbles by the slowly boiling nitrogen. This was done by electrical heating wires. Obstructions formed spontaneously (probably of ice) in the core and prevented light transmission.

2.2. Liquid Xe in a BaF₂ tube.

Liquid xenon has a refractive index (~ 1.5) that is higher than that of many solid materials whose infrared loss coefficients are much less than 1 cm^{-1} (as is necessary to serve as cladding around the liquid xenon to form a low-loss waveguide with $L \sim 10 \text{ m}$, at 10.6 microns). Such solids include: SrF₂ ($n \sim 1.4$), BaF₂ ($n \sim 1.3$), NaF ($n \sim 1.3$), and KF ($n \sim 1.3$). Inquiries suggested that, of these, BaF₂ is the easiest to fabricate.

Therefore, we constructed the guide shown in Fig. 4. However, the BaF₂ slabs broke continually under the thermal stress of cooling, even when efforts were taken to reduce stress by pre-cooling in cold nitrogen gas.

2.1.3. Liquid bromine.

We reproduced the liquid-bromine-in-glass infrared waveguide developed by Bridges, et al. (Optics Lett. 7, 566 Nov. 1982). Purification of the Bromine sufficient to achieve low absorption in a 2 m path was never achieved. A safety committee forbade the necessary extensive handling of the Bromine in our laboratory.

2.2. SBB in bulk liquid nitrogen.

The experimental setup is shown in Fig. 5. The source used was a pulsed CO₂ laser, model K-162 from Lumonics. A cw section inserted in the cavity served as a frequency selective element and produced single frequency pulses. The pulse duration of the forward beam monitored with a photon drag detector - Rofin model 7410, D1 in Fig. 1 - was 230×10^{-9} seconds, while the energy delivered per pulse, monitored with an Energy

Precision Model RJ-7200 energy meter was 50×10^{-6} Joules. The temporal profile of the pulse is shown in Fig. 6

An Infrared Red Associates liquid nitrogen HgCdTe detector monitored the backscattered signal. As shown in Fig. 5, the detector was placed in a screen room which provided electronic noise protection of up to 130 dB. The beam was directed to the screen room by a series of flat Cu mirrors. A spherical Cu mirror of radius $R=1\text{m}$ focused the beam in the bulk of liquid nitrogen contained in a Janis cryostat. The geometry of the experiment minimized back reflections of the forward beam. The calculated frequency shift of the SBS signal is 200 Mhz, a small number which made the use of spectral filters prohibitive at least at this stage of the experiment.

Fig. 7 shows two oscilloscope pictures of the forward (lower-trace) and backscattered pulse (upper-trace) under different experimental conditions. In Fig. 7a the backscattered pulse was recorded while the liquid nitrogen surface was blocked with a piece of cardboard placed at such an angle that direct back reflections of the forward beam could not reach the HgCdTe detector. In Fig. 7b, the beam is unobstructed, i.e., the backscattered beam comes from the liquid nitrogen. If there is a difference between between 7a and 7b it is the faster rise time of the unobstructed beam (7b). On the other hand, an SBS phase conjugated signal has all the coherent properties of a Gaussian laser beam, including the Gaussian spatial profile. Should then the backscattered signal be a phase conjugated SBS beam, a beam scan would reveal its Gaussian profile. The beam scan was performed by moving a slit, placed in front of the HgCdTe detector across the beam. The results were inconclusive, because we could never eliminate stray reflections. However, beam scans of the unobstructed beam revealed occasional high intensity spikes as if the signal was coming back in bursts. A similar behavior has been recorded in the detection of SBS pulses from laser produced plasma, where the SBS signal would also come in bursts and be significantly shorter (one order of magnitude) than the incoming

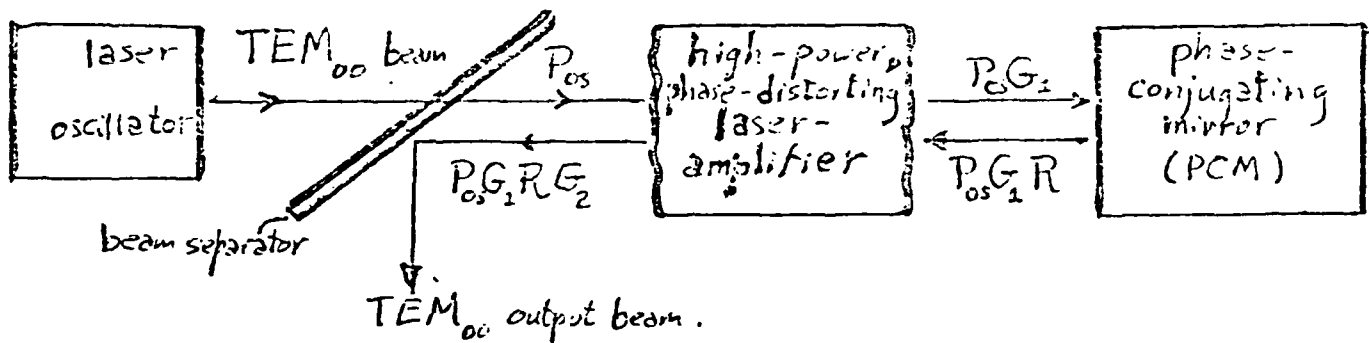
laser pulse

The results of this experiments are suggestive of the presence of an SBS phase conjugated signal. Further improvements, mainly in the spectral separation would produce unambiguous information.

In another series of experiments, we used a TV thermal imaging system. This system permits accurate measurements of the spatial distribution of I.R. laser beams. Part of the system is a tape recorder which is used to preserve on tapes the observed beam after the experiment. Fig. 8 shows the experimental set-up. The same geometry as in the previous experiment was used, with the backscattered beam being directed now to a flat Cu mirror so that the camera could focus on it. Fig. 9 shows a series of pictures of the backscattered beam distribution under different experimental conditions. In Fig. 9a, the forward beam is reflected from a piece of cardboard oriented so that the reflected beam could not reach the imaging mirror. In Fig. 9b the energy per pulse is low (10×10^{-6} Joules) while in Fig. 9c the energy per pulse is maximum (52×10^{-6} Joules) and in both cases the beam is scattered back from liquid Nitrogen. In the last case two bright spots are present - two because of the reflections on the front and back surface of the beam splitter. Since SBS is a threshold effect, the appearance of an intense back beam above a certain laser intensity is at least suggestive of the presence of SBS. It appears though, that even when operating at maximum energy per pulse, we are very near threshold, so that fluctuations in the energy could produce inconsistencies in the data. Currently, we are in the process of upgrading the laser system by adding an amplifier section which would increase the energy per pulse by at least fourfold.

Figure 1.

Proposed 'master-oscillator-power-amplifier (MOPA) configuration with phase-conjugating mirror (PCM)'.



P_{os} = power from single TEM₀₀ mode master oscillator.
(E.g., 1 Watt)

G_2 = small-signal gain of amplifier.
(E.g., 10^3)

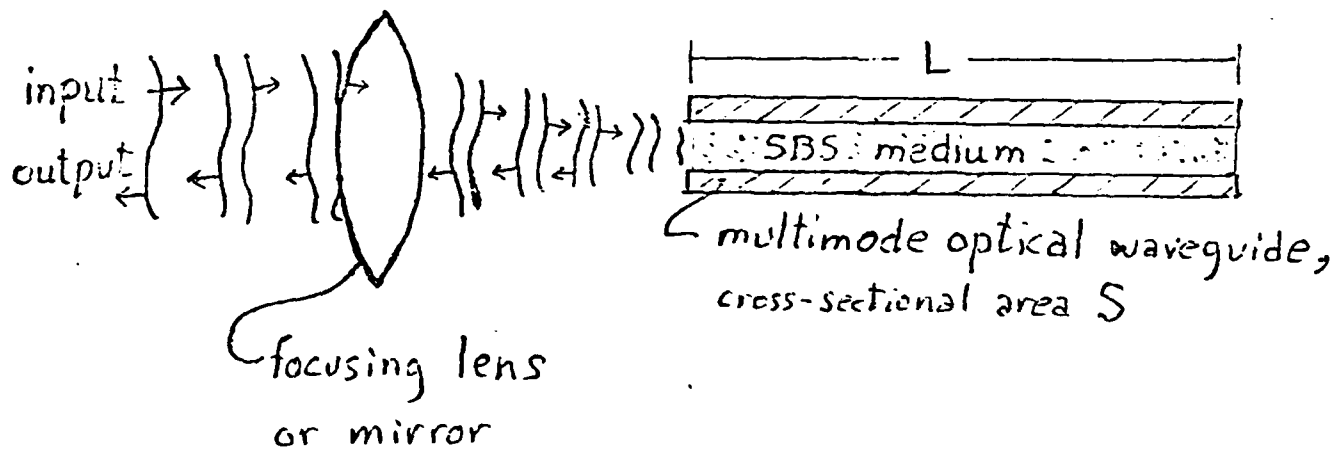
R = reflectivity of PCM.
(E.g., 0.8)

G_1 = large-signal gain of amplifier
(E.g., 10^2)

$P_{os}G_1RG_2$ = output power of MOPA-PCM
(E.g., 80 kW)

$P_{os}G_1$ = power to be phase-conjugated
(E.g., 1 kW)

Figure 2.



Schematic of phase-conjugating mirror.

Note: Unguided interaction where $S \rightarrow \infty$ is also known to produce phase-conjugation in some cases at higher power levels.

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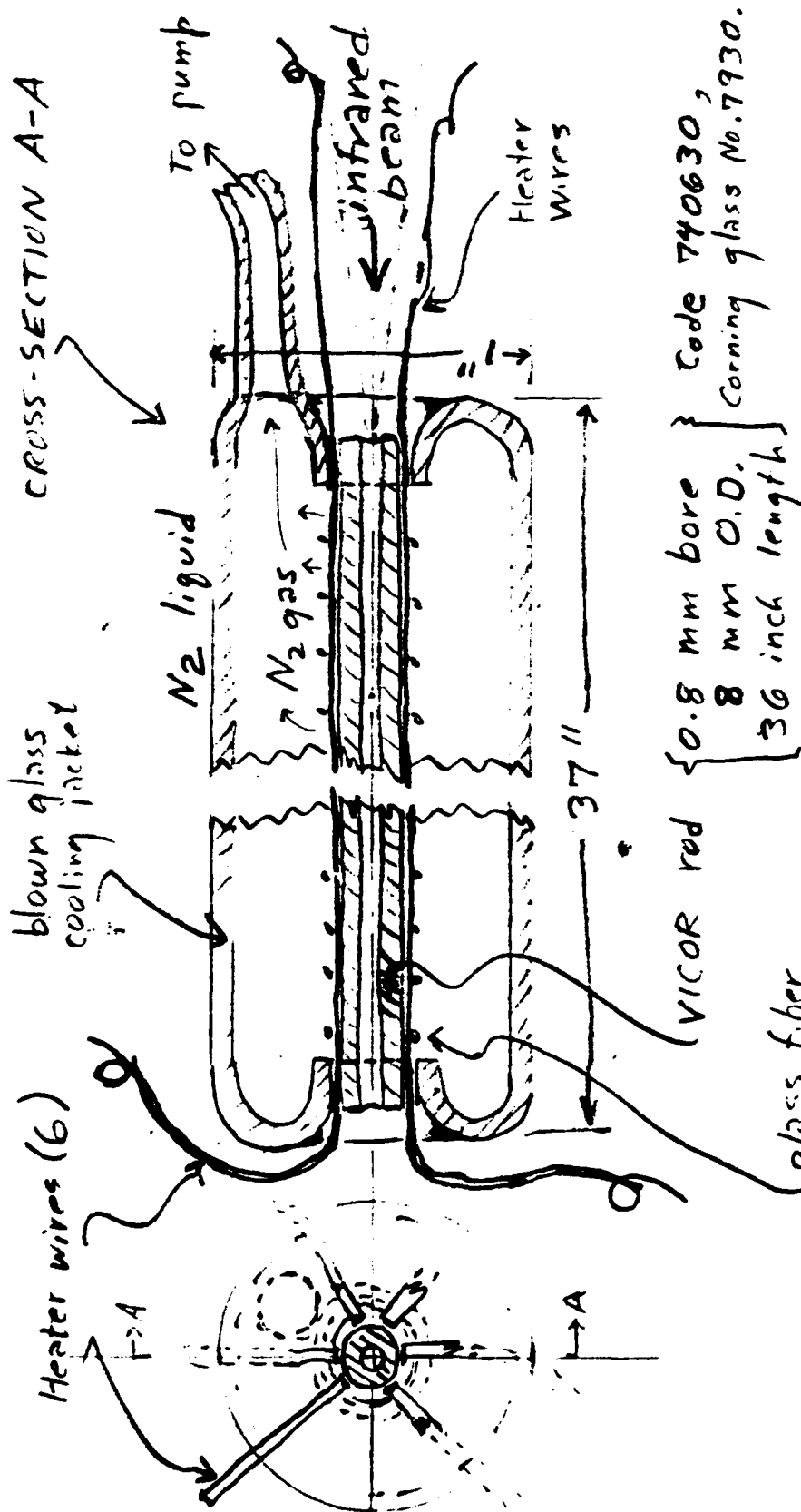


Figure 3

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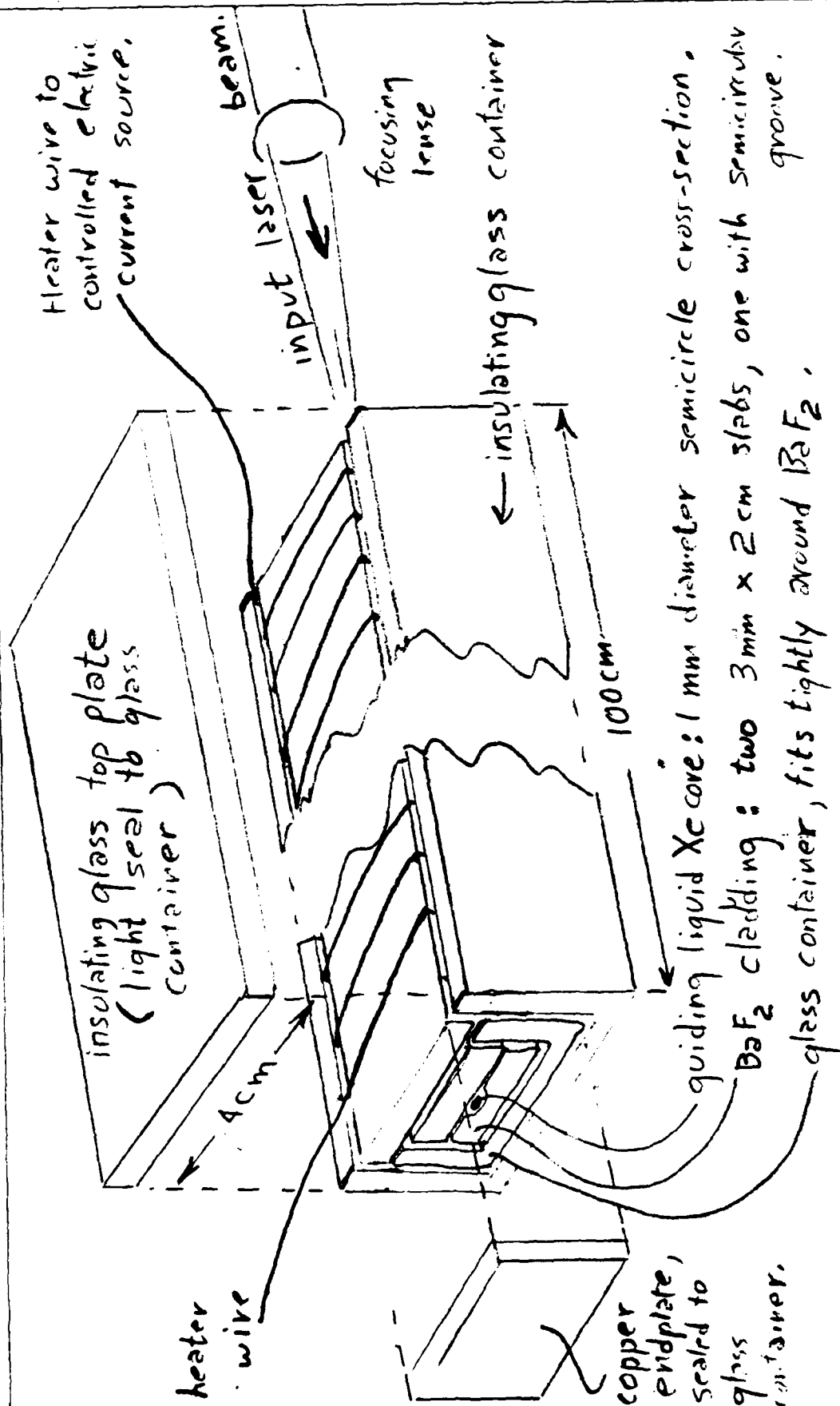
PAGE 12

SUBJECT

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This assembly is to be suspended in liquid nitrogen (77°K).
 Heater keeps Xenon core in liquid range (161 to 166°K).
 Glass container insulates heater from liquid nitrogen.

Figure 4

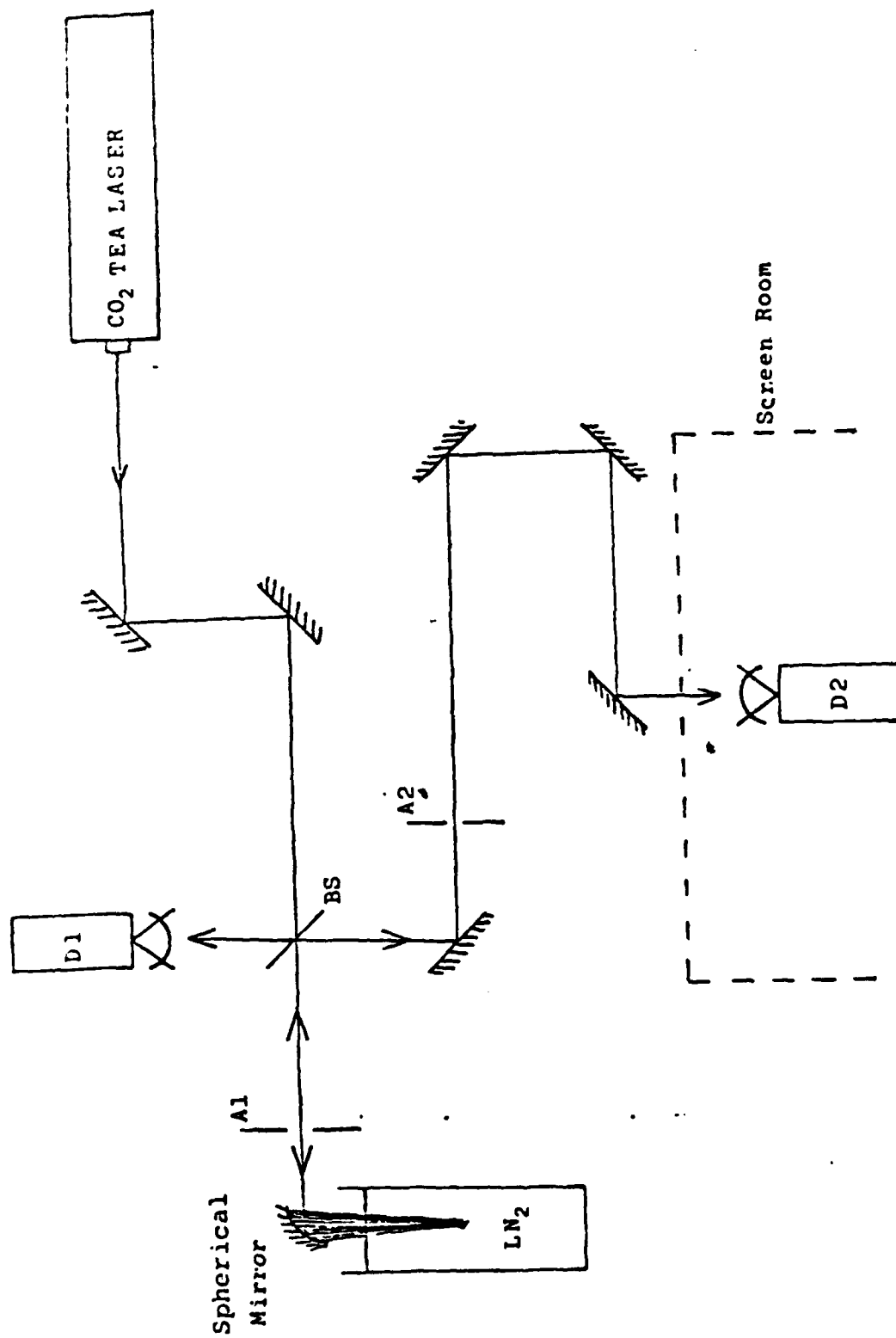
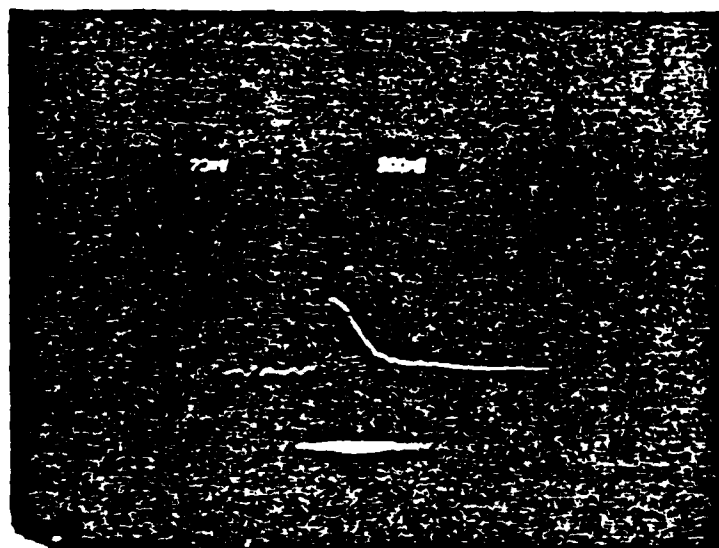


Fig. 5 - Experimental setup for SRS in bulk liquid nitrogen.

Fig. 6 - Temporal pulse shape of CCO_2 laser.



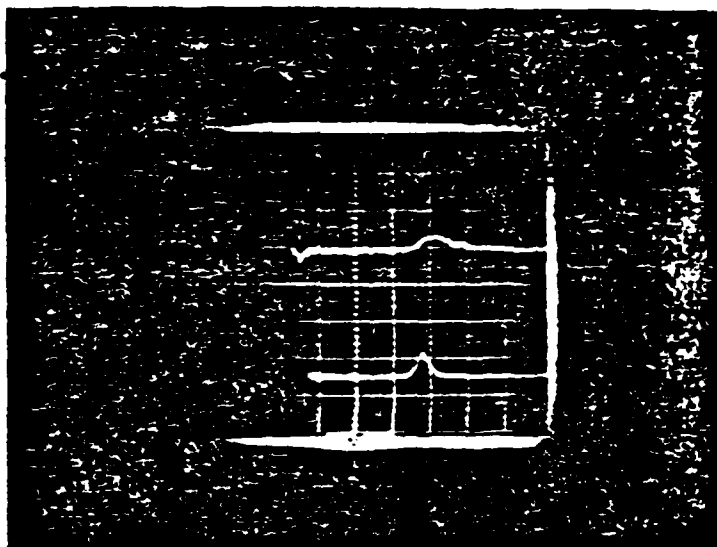
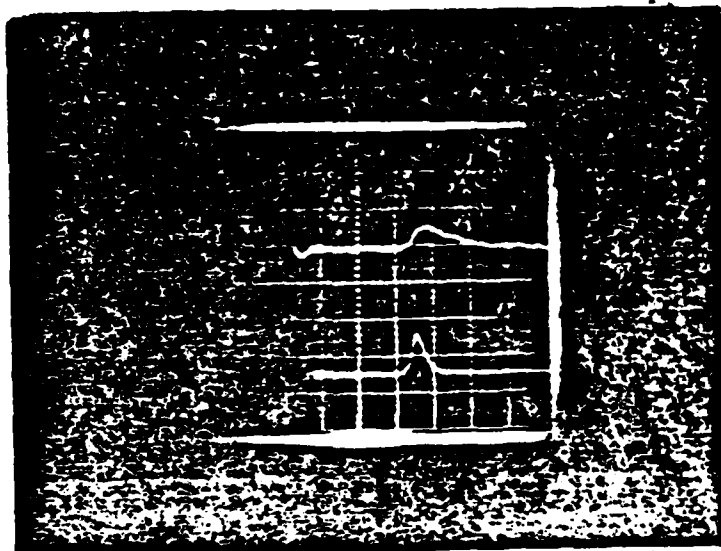


Fig. 7 - a) backscattered beam detected by the HgCdTe detector, after being reflected from a cardboard (lower trace). The upper trace shows the forward pulse detected by the photon drag detector.



b) backscattered beam detected by the HgCdTe detector, after being reflected from the liquid nitrogen (lower trace). The upper trace shows the forward pulse detected by the photon drag detector.

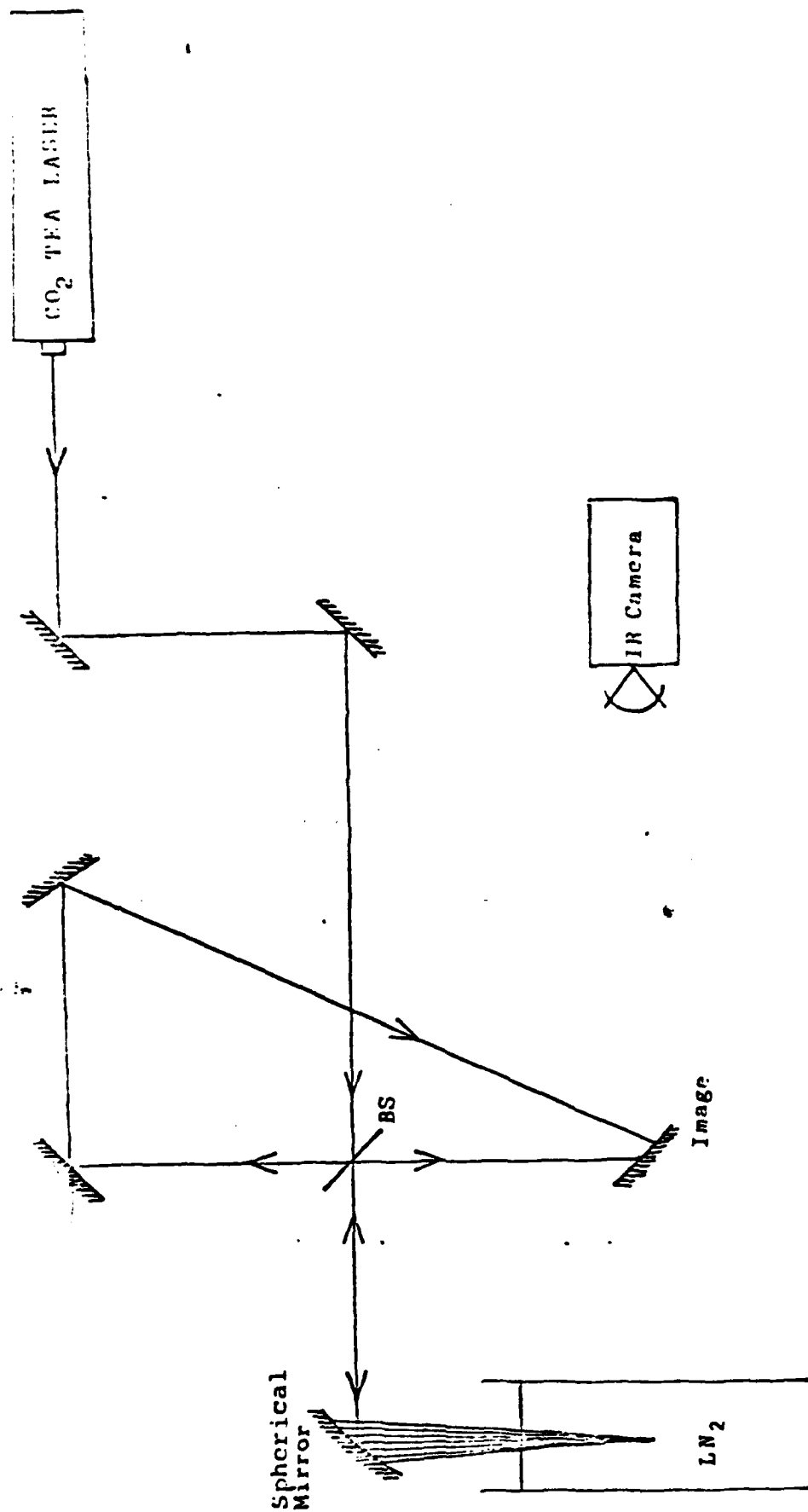


Fig. 8 - Experimental set up with the TV camera.

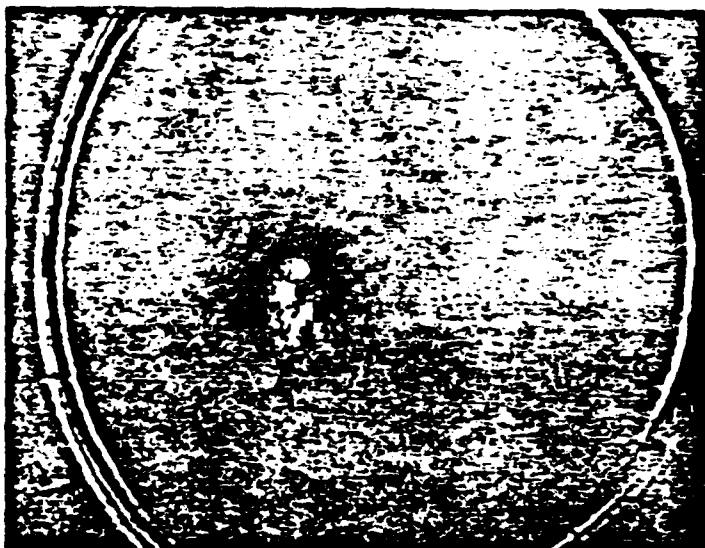
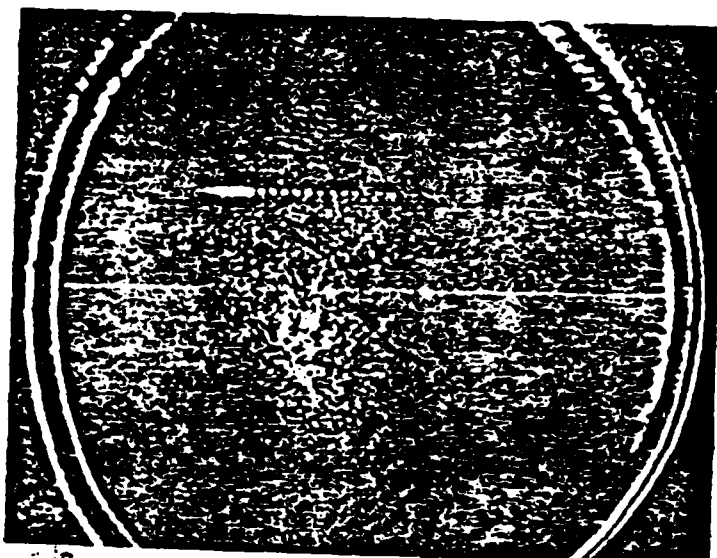
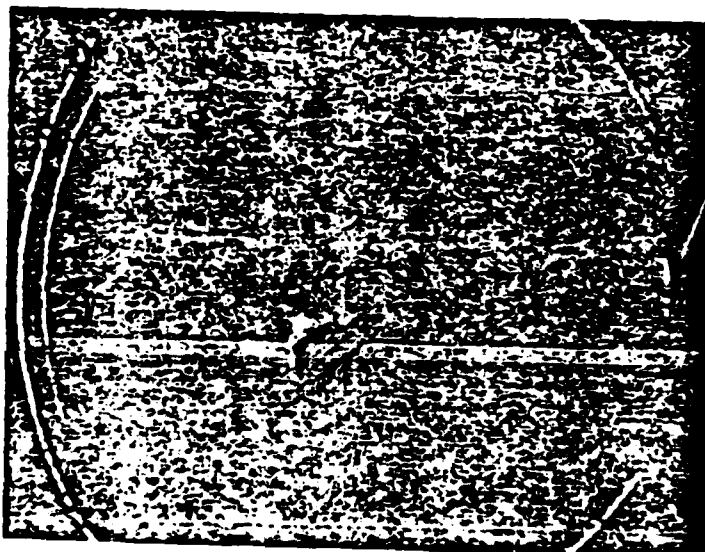


Fig. 9 - a) Backscattering from a cardboard.



b) Backscattering from liquid Nitrogen (low intensity).



c) Backscattering from liquid Nitrogen (high intensity).

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